GEOS-5: Global Modeling and Assimilation Development

Science Mission Directorate

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Project Goals and Objectives: The GEOS-5 system is being developed in the Global Modeling and Assimilation Office as a comprehensive model for both weather and climate applications, with an associated atmospheric data assimilation system (DAS) for satellite data synthesis. The longer-term goal is to develop a next-generation atmospheric data assimilation capability to meet NASA's goals of maximizing the use of satellite observations to advance our understanding of processes related to climate variability and change, improve our modeling and prediction of the Earth system, and define future Earth observing systems. The specific shorter-term objective is to conduct simulations, assimilations, and forecasts to prepare a well-tuned state-of-the-art system running at half-degree resolution for the atmospheric DAS and one-degree for climate applications. The DAS must support the MERRA reanalysis—a major reprocessing of all atmospheric data during the satellite era—and the forward processing needs of EOS instrument teams. The model must support the broader MAP science goals.

Project Description: Like all atmospheric assimilation systems the two main components of the GEOS-5 DAS are the atmospheric general circulation model (AGCM) and the analysis system. The GEOS-5 AGCM is the first major operational system built using ESMF and its object-oriented concepts. The analysis system is NOAA/NCEP's next generation analysis, the Grid-point Statistical Interpolation (GSI) analysis, now being developed with collaboration from the GMAO. This project has supported the implementation of Version 5 of the Goddard Earth Observation System model, GEOS-5, i.e., the coupling of the AGCM and the GSI, the tuning of the system, and experimentation to evaluate the impact of satellite data streams on numerical weather prediction skill.

Since the GEOS-5 AGCM is intended as an assimilation, weather prediction and climate model it must be tested and tuned in each of these configurations. The model must first perform well in stand alone simulations of the atmospheric climate, troposphere and stratosphere, with realistic variability on time-scales from subseasonal to interannual. It must also serve as an assimilation model, providing adequate background fields for the statistical analysis of observations and producing realistic diagnostics of poorly observed or unanalyzed quantities, such as precipitation and surface fluxes. It must perform well as a weather prediction model since this is one of the main criteria for assessing the quality of the analysis. It must also provide realistic and adequate time-varying and residual transport fields for use in coupling to atmospheric chemistry modules.

The statistics that are the backbone of the analysis system must be tuned for the AGCM used with it and for the new data types included in the analysis. This project has focused particularly on EOS/Aqua/AIRS and atmospheric polar winds derived from MODIS on both Aqua and Terra.

Advanced diagnostic tools, particularly those based on adjoint methods, are being developed to provide insight into the impacts of the observing system on metrics chosen for weather prediction. By comparing impacts of each observation set with expected impacts or with those from other operational systems, these tools also help with tuning of the system performance for weather prediction applications.

Relevance of Work to NASA: This project is a core element of NASA's Modeling, Analysis and Prediction (MAP) Program. The GEOS-5 system supports NASA's Earth science research in the synthesis of Earth satellite observations, in EOS instrument team products, in observing system modeling and design, in climate and weather prediction, and in chemistry-climate interactions.

Numerical and Computational Approach: Both the model and the analysis are finite-difference grid-point codes, written in Fortran-90. The GCM relies heavily on the Earth System Modeling Framework (ESMF) superstructure and infrastructure for its internal architecture. Parallelization is primarily MPI. The model runs on a 2-D decomposition, transposing internally between horizontal and vertical layouts. Some of the physics such as the solar radiation, which at any given time is active over only half the globe, is load balanced.

The code scales well and scalability increases linearly with problem size. At ½ degree and higher resolution, the code scales very well within an Altix node (up to 480 processors). As part of our experimentation on Columbia, we have attempted to run the ¼ degree model *across* nodes (up to 1920 processors for a single image). Overall the scaling is quite good even in this extreme use of Columbia.

Results: Using both NAS/Columbia and NCCS/Explore, we have been able to run many hundreds of simulations in weather, climate and assimilation modes. Runs were made at various resolutions, using different parameterizations and doing parameter sweeps. Since there are many uncertainties in the formulations of both the model and analysis system, and since most processes being modeled are highly interdependent, we are faced with an almost infinite number of combinations to be evaluated. Comprehensive diagnostics and a validation suite assembled for evaluation of our GEOS-5 system were used to guide the parameter sweeps and keep the number of experiments to a minimum.

The initial test-production version of GEOS-5 has been run globally at various resolutions, including a 1/4-degree resolution to support hurricane forecasts as part of MAP05. Simulations of Hurricane Katrina at 1, ½, and ¼-degree resolution show the importance of resolution in how the model is able to simulate the details of extreme mesoscale weather events (Figure 1). The performance of the model in climate simulations has been evaluated in 1-degree simulations. In this configuration, GEOS-5 has compared well with other national climate models.

The GEOS-5 DAS is still undergoing the last stages of tuning and the final implementation of fine details needed for well-balanced analysis states. Nevertheless, the test version of the DAS has demonstrated a credible analysis capability so that it has been used for initial tests of the impact of Aqua/AIRS on the statistics for global weather prediction skill. Using the data from 251 channels in all fields-of-view as input to the GSI, AIRS shows a positive impact on 500 hPa forecast height in both hemispheres (Figure 2).

Adjoints have been developed for both the AGCM dynamics with simple physics and for the GSI. Together these provide powerful diagnostic tools which can relate errors in forecasts, according to a chosen metric, to errors in initial conditions generated by the DAS, and then ultimately to back to individual observations. Using these tools, the impact of particular observations in improving forecast skill can be evaluated in the context of the entire observing system. Thus, the interplay and compensating roles of the different observations can be brought to light. As an example, the sensitivity of a 24-hour forecast, summarized in a global metric, to analyzed potential temperature at 600 hPa is shown in Figure 3. The corresponding influence of observations in an AMSU-A channel that peaks near that level is also shown. This is just a single example. A more comprehensive view requires more experiments for statistical reliability. Such experiments have been conducted for January and July 2005. The summary of observation impacts for July 2005 is shown in Figure 4, showing the importance of satellite observations in the Southern Hemisphere, and the relative importance of AIRS. These sorts of results need to be investigated with our updated, tuned system, and compared with other operational systems to evaluate the robustness of the results.

Role of High-End Computing: Models and assimilation systems are integrating tools that expand the usefulness of satellite observations. However, these systems have to be tuned to make optimal use of the data. Earth system models are not simply theoretical tools. The confrontation with data not only readily exposes deficiencies in the system, but also provides a powerful potential for rectifying those deficiencies. To do so requires a lot of experimentation at high resolution. These sorts of experiments, both numerous and computationally intense, can only be carried out on massively parallel systems such as Columbia and Explore.

Future: The experimentation required to improve the model and analysis system is unending – the societal benefit to be gained by improved weather and climate prediction provides the imperative. In addition, the information to be gained about the existing observing system and about the potential impact of planned new observations is invaluable. Thus, we plan to continue to improve the GEOS-5 system, to generate meterological products in support of NASA instrument teams, to conduct high resolution simulations in support of hurricane prediction during 2006, and to prepare for the next generation comprehensive Earth system model and analysis system.

Publications:

X. Lin, J.-L. Li, M.J. Suarez, A.M. Tompkins, D.E. Waliser, M.M. Rienecker, J. Bacmeister, J. Jiang, H.-T. Wu, C.M. Tassone, J. D. Chern, B. D. Chen, H. Su, “A View of Hurricane Katrina with Early 21st Century Technology”, *EOS, Trans. AGU* (to appear).

M. Rienecker, P. Arkin, M. Suarez, R. Todling, R. Gelaro, J. Bacmeister, S. Schubert, M. Bosilovich, “MERRA and US Reanalysis Plans and Activities”, *ECMWF/GEO Workshop on Atmospheric Reanalysis* (to appear).

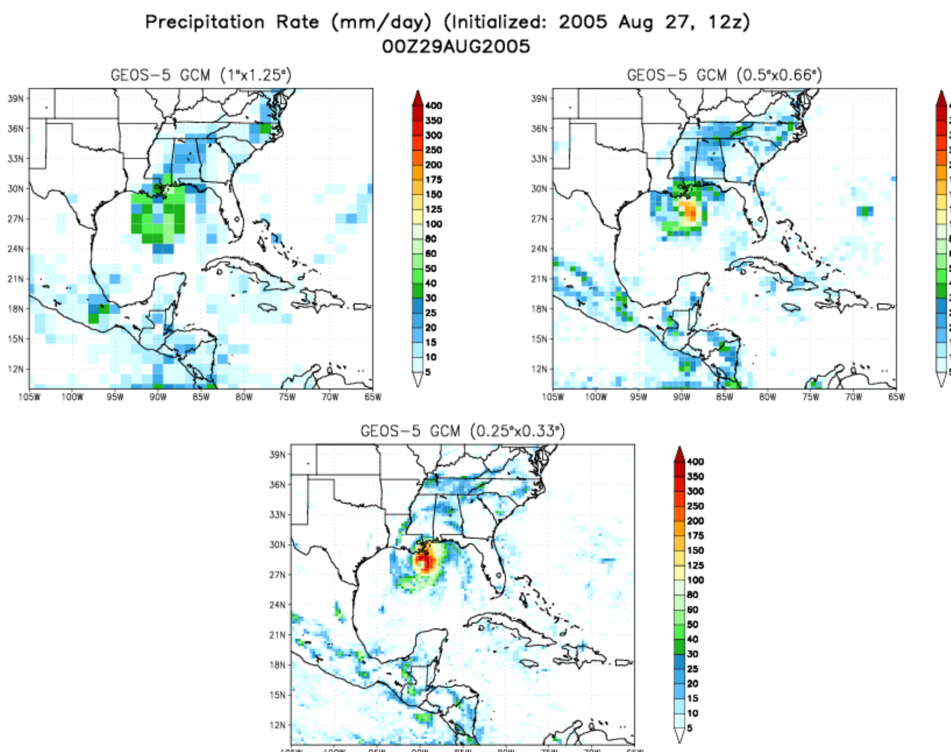

Figure 1: Forecast precipitation rate from a 2-day forecast before Hurricane Katrina made landfall, from the version of GEOS-5 used during MAP05. The upper left-hand panel is from a 1-degree resolution forecast; the right-hand panel is from a ½-degree resolution forecast; and the lower panel is from a ¼ degree resolution forecast. All forecasts are initialized from the NOAA/NCEP operational forecast at approximately 35-km resolution. (Figure courtesy of Larry Takacs.)

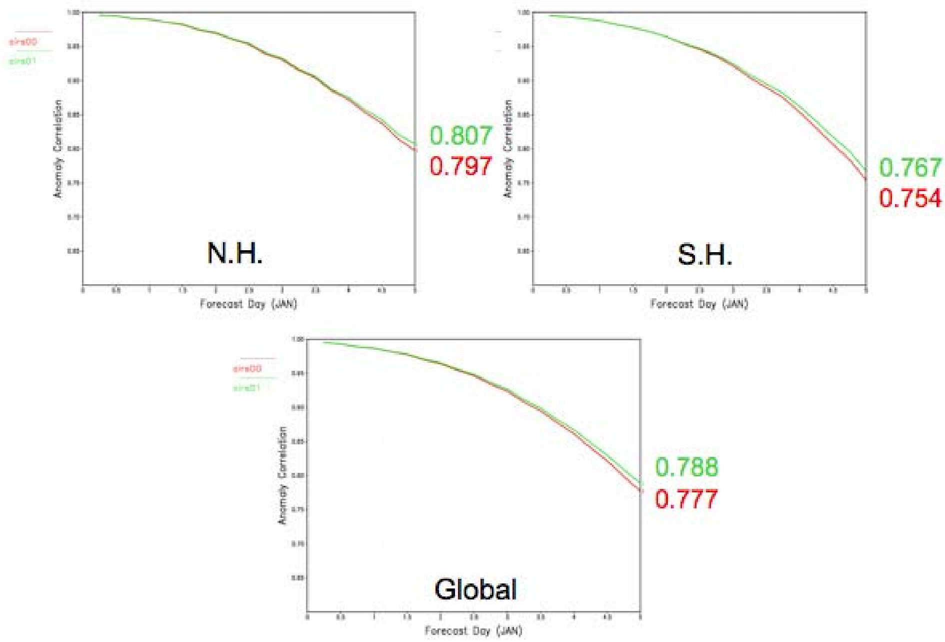

Figure 2: Impact of AIRS data on 500 hPa forecasts from a test-version of the ½-degree GEOS-5 system as measured by anomaly correlation as a function of forecast day, up to 5-day forecasts. The statistics, based on 30 forecasts conducted during January 2006, are shown for the separate hemispheres as well as for the globe. The green (red) curves are forecasts from analyses that do (do not) include AIRS radiance data. A greater impact is found in the Southern Hemisphere where satellite data are crucial parts of the observing system. (Figure courtesy of Emily Hui-Chun Liu.)

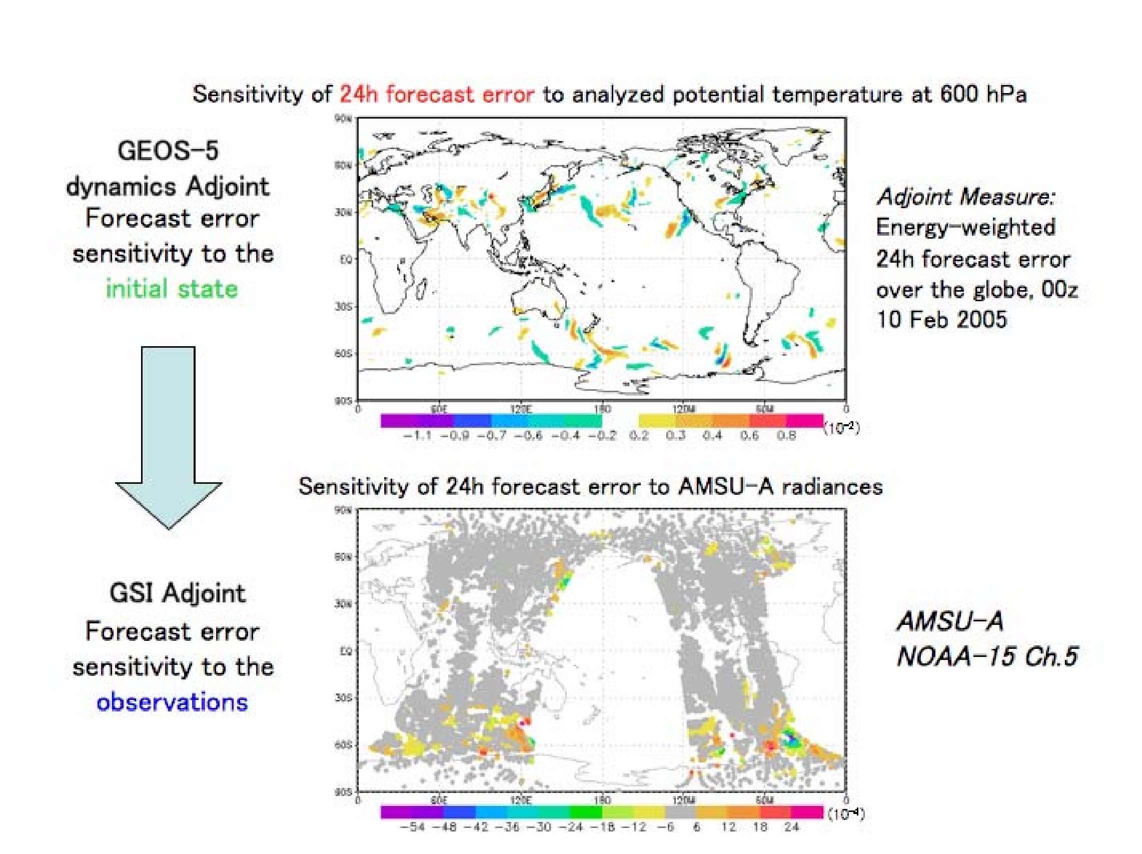

Figure 3: Sensitivity of the 24-hour forecast error on 10 February 2005 to individual observations from AMSU-A Channel 5 on NOAA-15, computed using the adjoint of the fv-dynamics in GEOS-5 and the adjoint of the GSI.

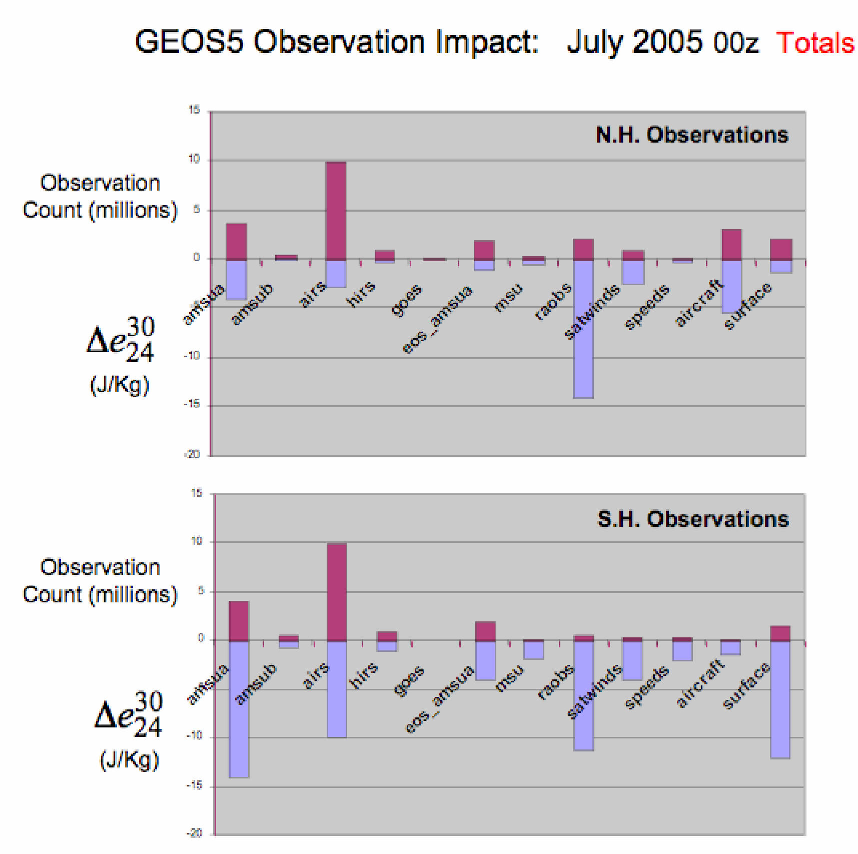

Figure 4. Summary of observation impacts on 24-hour forecasts according to observation type in the GEOS-5 test system for July 2005.